Chapter 8

Suspension-Bridge Design

Suspension bridges can span distances from 2,000 to 7,000 feet, which is far longer than any other kind of bridge. They also tend to be the most expensive to build. True to their name, suspension bridges suspend the roadway from huge main cables, which extend from one end of the bridge to the other. These cables rest on top of high towers and are secured at each end by anchorages. The towers enable the main cables to be draped over long distances.

DESCRIPTIONS

8-1. Suspension bridges have two basic systems–main cables supported by towers at each end over the obstacle and a roadway suspended from the main cables *(Figure 8-1, page 8-2)*. Suspender cables support the floor beams, which support the stringers that support the roadway. Stiffening trusses further spread the live load to the suspenders. Suspension-bridge design requires analysis of the following items:

- Load to be carried.
- Panel length.
- Floor beams and stringers.
- Stiffening trusses.
- Dead load.
- Suspenders.
- Main cables.
- Towers.
- Tower bracing and backstays.
- Anchorages.

UNSTIFFENED BRIDGES

8-2. Unstiffened bridges consist of floors, without stiffening trusses or girders, suspended from cables. These bridges are suitable only where live load or wind load can never cause serious deformation of the cable. An example of this type of bridge would be a footbridge, where the live load is very light. Other examples are structures with a large dead load but insignificant live load.

STIFFENED BRIDGES

8-3. Stiffened bridges have flexible cables that are stiffened by suspended girders or trusses. These bridges minimize local changes in roadway slope due

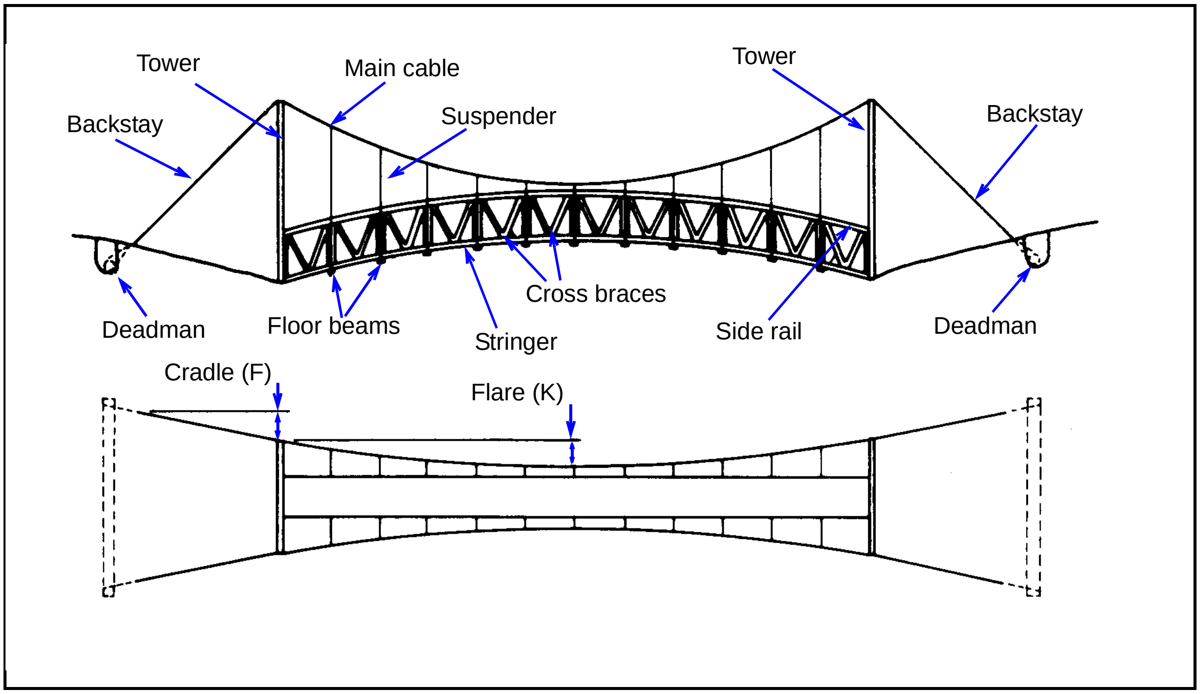

Figure 8-1. Suspension Bridge

to live loads. They are constructed by framing the floor beams of the floor system into stiffening trusses and supporting these trusses with hangers running to the cables.

SELF-ANCHORED BRIDGES

8-4. Self-anchored bridges are supported on vertical foundations, and no anchor cable is required. The horizontal force on the main cable is exerted by endwise thrusts in the stiffening girder.

MULTIPLE-SPAN BRIDGES

8-5. Multiple-span bridges are a combination of two or more adjoining suspension bridges sharing a common anchorage. The towers of these bridges are connected by a tie cable to restrain movement of the tower tops from unbalanced live loads.

BRIDGE SITES

8-6. The selection of a bridge site is very critical. Factors to consider when determining a bridge site are the tower spacing, the bridge clearance, and the work area.

TOWER SPACING

8-7. Keep the distance between towers as short as possible (not more than 400 feet). Also, keep the towers at the same elevation if possible. Long spans with a considerable difference in tower elevations require large wire ropes and increase material-acquisition problems. Longer spans also may increase cable tension, requiring heavier towers and anchorages and increasing construction effort. There should be minimal differences in the tower and the bank elevations.

BRIDGE CLEARANCE AND WORK AREAS

8-8. Avoid high points between towers for adequate clearance due to cable sag. When determining clearance, consider sag based on anticipated loads. Select a fairly level space around each tower. For clearance purposes, select a sharp slope just past the loading area.

DESIGN FACTORS

8-9. Factors to consider when designing a suspension bridge are the sag ratio, the camber, the cradle and flare, and the backstay slope. *Figure 8-2* shows the suspension-bridge design factors.

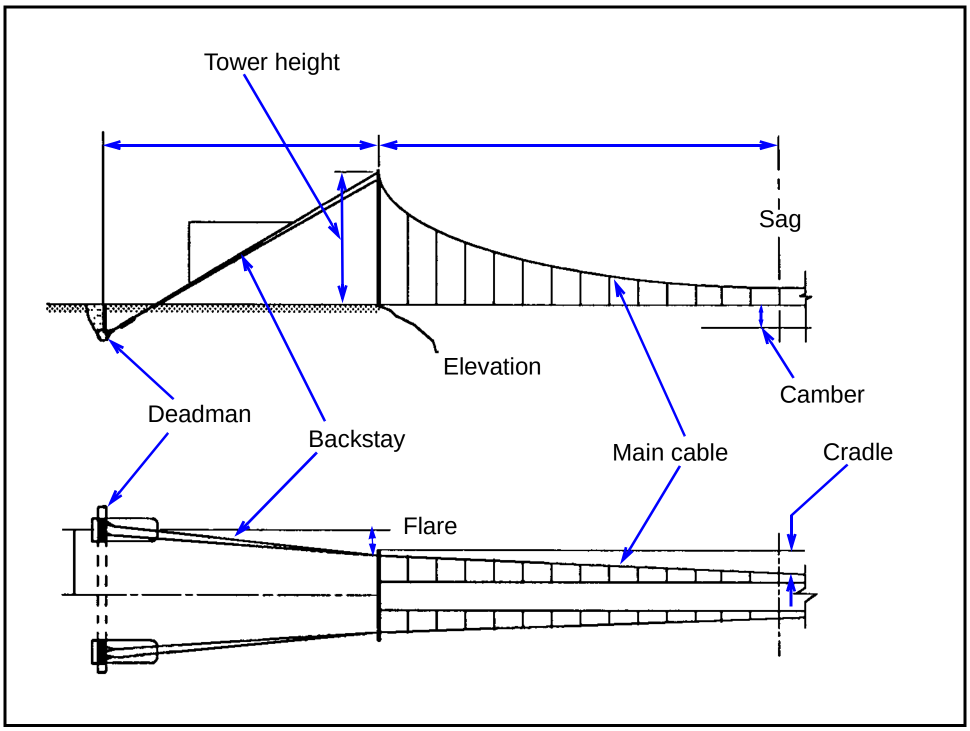

Figure 8-2. Suspension-Bridge Design Factors

SAG RATIO

8-10. Sag controls the length and stability of the bridge. The sag ratio varies from 5 to 16.66 percent. The sag ratio is computed by dividing the sag by the span length. If the main cables have a flat curve or low sag ratio, the bridge has more vertical stability but the cable stress is high and strong anchorages are required. If the sag ratio is high, the cable is under less stress and anchorages may be placed closer to the towers.

CAMBER

8-11. Camber is the vertical distance between the top of the floor beam at the midspan and a straight line drawn between the tops of the tower sills. Camber allows for deflection of a bridge when loaded. The camber should be equal to 0.67 percent of the span length.

CRADLE AND FLARE

8-12. Cradle is the lateral distance from the midpoint of one of the main cables to a straight line drawn between its support points on the towers. Flare is the lateral distance from the cable support on the tower to the anchorage. The cradle should be equal to 1.25 percent of half the span length. The flare should be between 2.5 and 3.5 percent of the horizontal backstay length. Both cradle and flare help steady a bridge.

BACKSTAY SLOPE

8-13. Backstay slope is the ratio of the vertical difference between the deadman and the tower support of the main cable to the difference in elevation between the deadman and the tower. The angle of the backstay and main cable may be the same. If so, the stress will be equal on both sides of the tower. The backstay slope is usually a 1:2.5 ratio.

LIVE LOAD

8-14. Use either a uniform or concentrated load condition when designing suspension bridges. If five or more concentrated loads are carried on the bridge at one time, consider this load as a uniform load condition to simplify the design process. Use the dead and live loads when designing floor and side-rail systems. Use the dead, live, and impact loads when designing the cable system. Assume the impact load to be 100 percent of the live load.

PANELS

8-15. *Figure 8-3* shows a typical suspension-bridge panel. A truss helps spread the load over several panels and stabilizes a bridge. When the truss is omitted, suspend the roadway and posts from the main cables.

LENGTH

8-16. Assume a panel length between 10 and 15 feet to start the design process. A 10-foot panel is usually a practical length. Number the panels symmetrically from zero at the center suspender to the number of panels needed to reach the towers (*Figure 8-4)*. A design is simplified if there is an even number of panel points, thus dividing the bridge exactly in half. Otherwise, number the panel points by halves (0.5, 1.5, 2.5, and so forth), beginning with the panel closest to the center span.

STRINGERS

8-17. Use *Table 8-1, page 8-6,* to select the nominal stringer size. This table assumes uniform loading and uses an allowable bending stress of 1 ksi. If

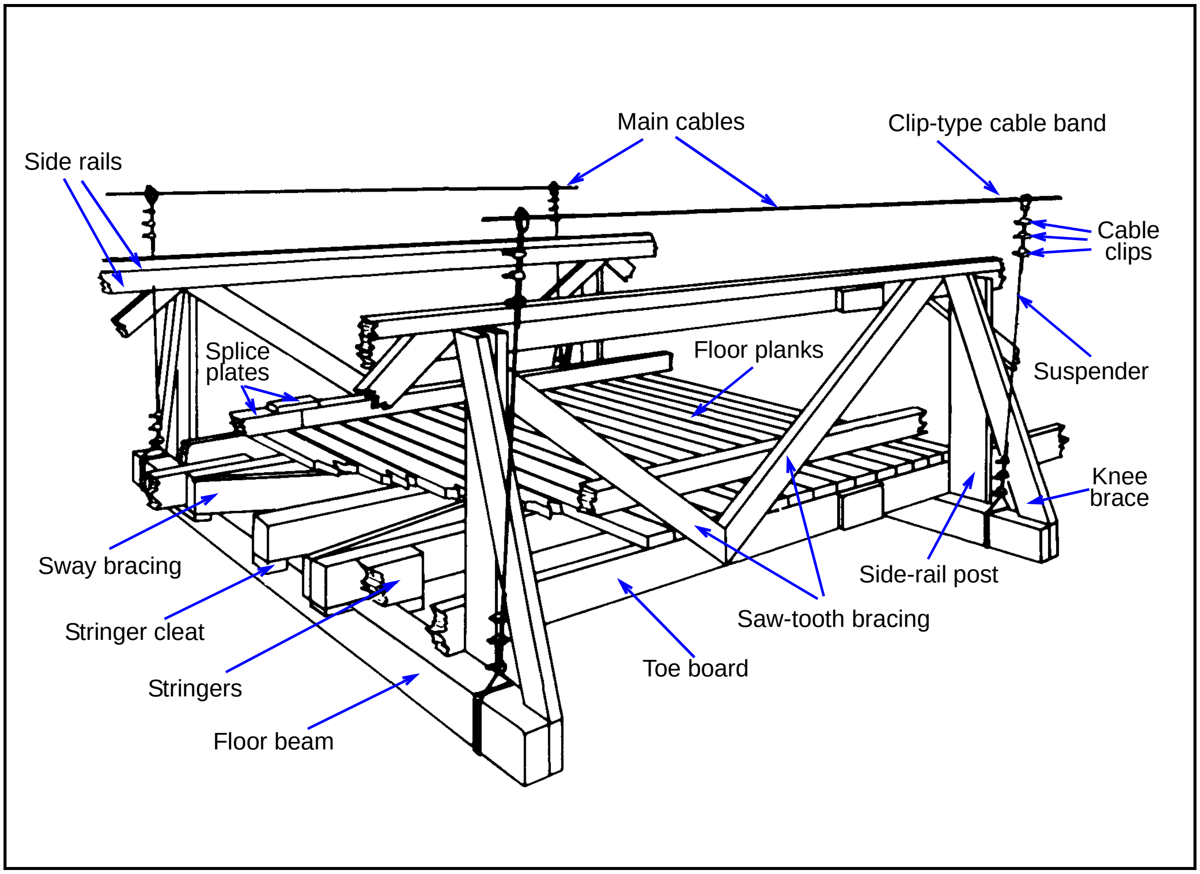

Figure 8-3. Typical Suspension-Bridge Panel

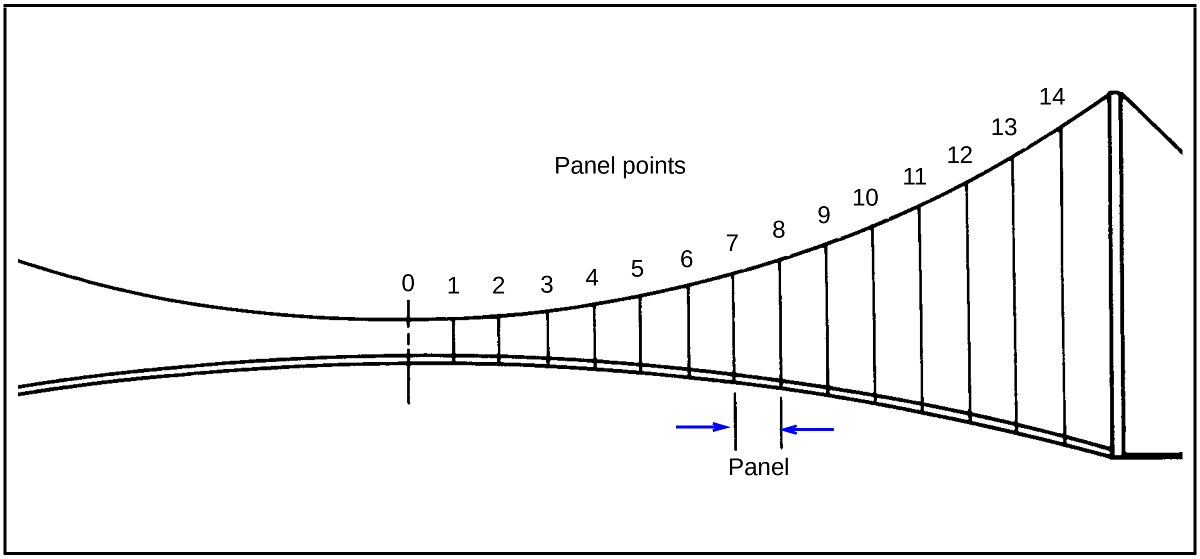

Figure 8-4. Panel Points

designing a bridge for a concentrated load, use half the load value selected from this table. For bending stresses other than 1 ksi, multiply the load in *Table 8-1* by the new allowable bending stress. The allowable bending stress for timber is shown in *Table C-1, pages C-3* through *C-6*.

Table 8-1. Properties of Wooden Beams

1	2	3	4	5
Nominal Size (in)	**Actual Size (in)**	**Area of the Section (sq in)**	**Weight per Linear Foot (w)[1]**	**Maximum Safe Uniform Load (f_b)[2]**
4 x 6	3 5/8 x 5 5/8	20.4	5.66	12,740
6 x 6	5 1/2 x 5 1/2	30.3	8.40	18,490
4 x 8	3 5/8 x 7 1/2	27.2	7.55	22,700
6 x 8	5 1/2 x 7 1/2	41.3	11.40	34,400
8 x 8	7 1/2 x 7 1/2	56.3	15.60	46,900
6 x 10	5 1/2 x 9 1/2	52.3	14.50	55,200
8 x 10	7 1/2 x 9 1/2	71.3	19.80	75,200
10 x 10	9 1/2 x 9 1/2	90.3	25.00	95,300
6 x 12	5 1/2 x 11 1/2	63.3	17.50	80,000
8 x 12	7 1/2 x 11 1/2	86.3	23.90	110,200
10 x 12	9 1/2 x 11 1/2	109.3	30.30	139,600
12 x 12	11 1/2 x 11 1/2	132.3	36.70	169,000

NOTES:
1. The weight per linear foot (w) equals 40 pounds per cubic foot.
2. Based on the bending of a 1-foot span, f_b equals ksi.

FLOOR BEAMS

8-18. *Table 8-2* lists floor-beam sizes for various loading conditions. Design the floor beams so that the suspenders wrap around the floor beams. Extend the beams beyond the width of the roadway so that knee braces can be added to support the side-rail posts.

Table 8-2. Floor-Beam Sizes

Load	Floor-Beam Cross Section (in)
Foot troops with full packs	4 x 6
1/4-ton truck, normal load	6 x 6
3/4-ton truck, normal load	8 x 8

PLANKS

8-19. Use 2-inch planks for footbridges. Use 3-inch planks for light vehicle bridges.

SIDE RAILS AND POSTS

8-20. Side rails are not necessary on very light or short footbridges. As the span and the load increase, add side rails to stabilize the bridge. Use 2- x 4-inch posts and a single side rail for light footbridges. Use 3- x 6-inch posts with double side rails and a toe board for vehicle bridges. Make the posts about 42 inches long for safety and convenience.

BRACING

8-21. Saw-toothed bracing helps stiffen the truss and spread the load over several panels. Use 2- x 6-inch lumber for saw-toothed bracing. Knee bracing holds the posts and floor beams. Extend the floor beams to allow for the knee braces. Use 2- x 4-inch material. Sway bracing helps stabilize the bridge laterally. On light bridges, heavy-gauge wire with rack sticks *(Figure 8-5)* is sufficient. Heavier bridges require timber sway bracing *(Figure 8-6, page 8-8)*.

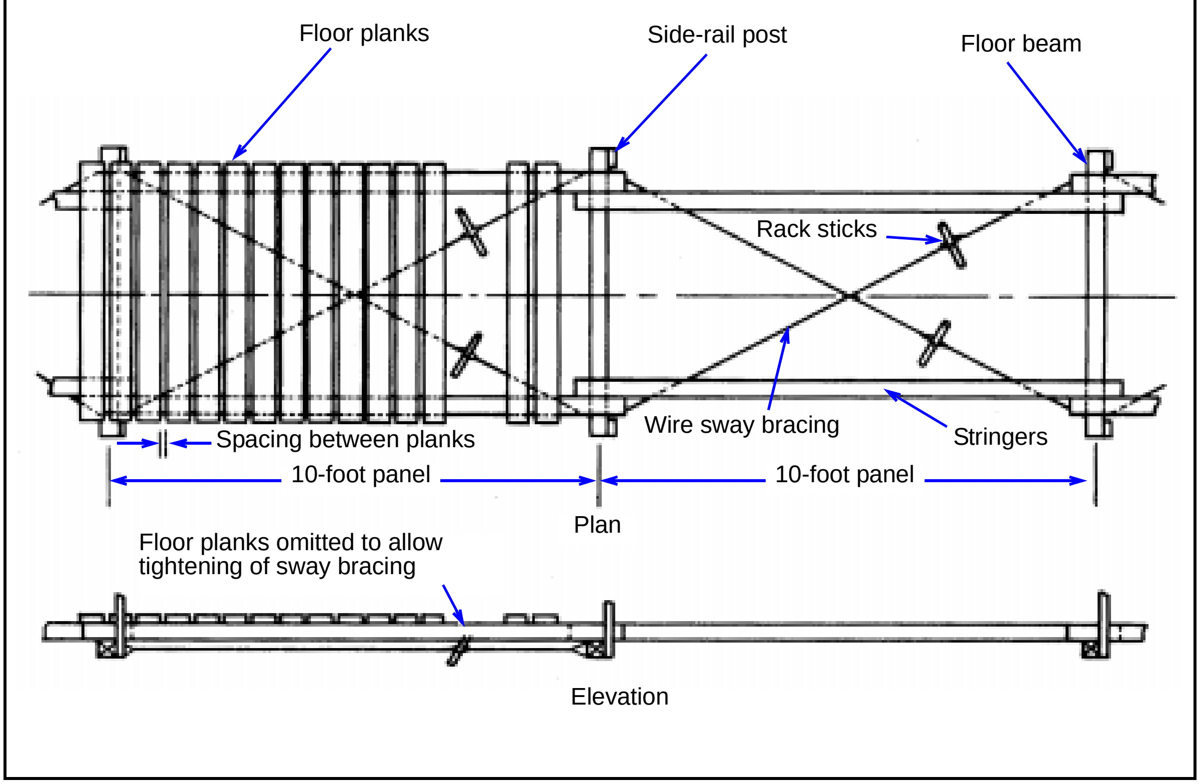

Figure 8-5. Wire Sway Bracing

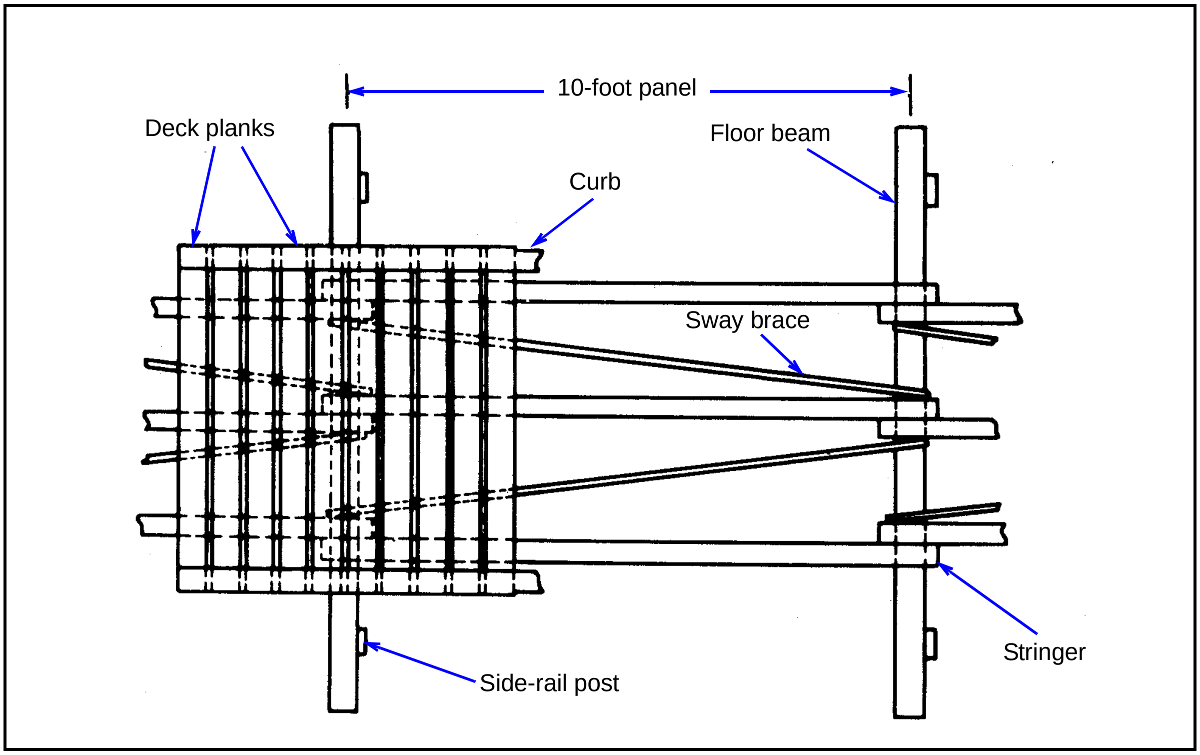

Figure 8-6. Timber Sway Bracing

DEAD LOAD

8-22. After selecting the truss and floor system, determine the dead load. To find the dead load of a panel, add the weight of the components (suspenders, floor beam, deck planks, stringers, toe boards, side-rail posts, knee braces, side rails, curbs, and clips). The dead load is measured in kips per panel.

SUSPENDERS

8-23. Suspenders carry the live, dead, and impact loads. Assume that the live load equals the gross weight of the traffic using the bridge. Determine the dead load according to *paragraph 8-22*. For design purposes, the impact load equals the live load. Use *Table 8-1, page 8-6,* and a safety factor of 5 to determine the allowable load per suspender. Compute as follows:

$$P_s = \frac{P}{N} \tag{8-1}$$

where—

P_s = *load per suspender, in kips*

P = *total load, in kips. The total load is the dead-load weight of all components plus the live-load weight designed for plus impact. Impact is the same as the live-load weight.*

N = *number of suspenders*

8-24. The effective suspender length is the distance between the main cable and the floor beam. Add sufficient length to each suspender to accommodate connections at each end. Compute the suspender length as follows:

$$d = L_{es} + \left(\frac{n}{n_t}\right)^2 (c + y_s) \tag{8-2}$$

where—

d = *distance between the main cable and the floor beam, in feet*
L_{es} = *effective length of the center suspender, in feet*
n = *panel point of the suspender (paragraph 8-16)*
c = *cable camber, in feet (paragraph 8-11)*
y_s = *cable sag (Figure 8-2, page 8-3)*
n_t = *panel point of the tower (paragraph 8-16)*

8-25. An additional 5 to 6 feet is adequate for connections with the main cable and the floor beams. The loop must include a thimble to prevent the main cable from shearing the suspender cable.

MAIN CABLES

8-26. Use *equations 8-3* through *8-10* or *Table 8-3, page 8-10*, to design the main cables. Assume a cable size to determine the dead load. Determine the cable tension and adjust the cable to accommodate the tension. Redetermine the cable tension (based on the new cable size) and check the cable's strength. Continue this process until a suitable cable size can be selected. Design a main cable as discussed below.

NORMAL DESIGN

8-27. The normal-design process is as follows:

- **Loads.**

$$W_c = \frac{P}{L} \tag{8-3}$$

where—

W_c = *weight per foot of main cable, in kpf*
P = *total load, in kips (paragraph 8-23)*
L = *span length, in feet*

- **Horizontal tension.**

$$T = \frac{W_c(L^2)}{8y_s} \tag{8-4}$$

where—

T = *horizontal tension, in kips*
W_c = *weight per foot of main cable, in kips (equation 8-3)*
L = *span length, in feet*
y_s = *cable sag, in feet (paragraph 8-10)*

Table 8-3. Cable-Design Data

1	2	3	4
Sag Ratio (y_S / L)	**Tension Factor[1] (x_t)**	**Tension Factor[2] (x_t)**	**Length Factor[3] (x_t)**
5	2.55	2.55	1.007
7	2.14	2.14	1.010
8	1.64	1.64	1.013
9	1.48	1.49	1.017
10	1.35	1.36	1.026
11	1.24	1.26	1.031
12	1.16	1.18	1.037
13	1.08	1.11	1.043
14	1.02	1.05	1.050
15	0.97	1.01	1.057
20	0.80	0.88	1.098

NOTES:

1. When the weight per foot of span is known, $T' = W_S(x_t)$.

2. When the weight per foot of cable is known, $T' = W_S(x_t)$.

3. The suspender length is $L_S = L(x_t)$.

LEGEND:

L = span length, in feet

L_S = suspender length, in feet

T′ = cable tension, in kips

W_S = stringer weight, in kpf

y_S = cable sag

- **Slope.**

$$\theta = \tan^{-1}\left(\frac{4y_s}{L}\right) \tag{8-5}$$

where—

θ = *cable deflection angle*
$\tan^{-1}$ = *inverse tangent function*
y_s = *cable sag, in feet (paragraph 8-10)*
L = *span length, in feet*

- **Tension in all cables.**

$$T' = \frac{T}{\cos\theta} \tag{8-6}$$

where—

T' = *cable tension, in kips*
T = *horizontal tension, in kips (equation 8-4)*
θ = *cable deflection angle (equation 8-5)*

- **Allowable tension in one cable.**

$$T_c = \frac{T'}{N} \qquad (8\text{-}7)$$

where—

T_c = *allowable tension per cable, in kips*
T' = *cable tension, in kips (equation 8-6)*
N = *number of cables*

- **Cable length.**

$$L_{ca} = L\left[1 + \left(\frac{8}{3}\right)\left(\frac{y_s}{L}\right)^2\right] \qquad (8\text{-}8)$$

where—

L_{ca} = *total cable length, in feet*
L = *span length, in feet*
y_s = *cable sag (paragraph 8-10)*

TABLE METHOD (EXPEDIENT)

8-28. Use *Table 8-3* to determine the cable tension factor and the cable length factor. Locate the appropriate sag ratio on the left-hand side and read to the right to Column 2 or 3, whichever applies. Compute the cable tension, length, and size and the number of cables required as follows:

- **Cable tension.**

$$T' = W_{DL}L(x_t) \qquad (8\text{-}9)$$

where—

T' = *cable tension, in kips*
W_{DL} = *dead-load weight of the span (Table 8-3, Column 2) or per foot of cable (Table 8-3, Column 3), in kpf*
L = *span length, in feet*
x_t = *factor from Table 8-3, Column 2 or 3*

- **Cable length.**

$$L_{ca} = L(x_t) \qquad (8\text{-}10)$$

where—

L_{ca} = *cable length, in feet*
L = *span length, in feet*
x_t = *factor from Table 8-3, Column 4*

- **Cable size.** Find the tension that all the cables must hold *(equation 8-6)* and the tension in each cable *(equation 8-9)*. Next, find the size of cable or wire rope and its corresponding breaking strength *(Table 8-4, page 8-12)*.

- **Number of cables required.**

$$N = \frac{T_c}{T_s} \quad (8\text{-}11)$$

where—

N = *number of cables required*
T_c = *amount of tension in the main cable due to the bridge load, in kips (equation 8-7)*
T_s = *breaking strength of the cable, in kips (Table 8-4)*

Table 8-4. Cable Properties

Diameter (in)	Improved Plow-Steel (IPS) Rope					
	6 x 7		6 x 19		6 x 27	
	Weight per Foot (lb)	Breaking Strength (tons)	Weight per Foot (lb)	Breaking Strength (tons)	Weight per Foot (lb)	Breaking Strength (tons)
1/4	0.094	2.64	0.10	2.74	0.10	2.59
3/8	0.210	5.86	0.23	6.30	0.22	5.77
1/2	0.380	10.30	0.40	10.80	0.39	10.20
5/8	0.590	15.90	0.63	16.60	0.61	15.80
3/4	0.840	22.70	0.90	23.70	0.87	22.60
7/8	1.150	30.70	1.23	32.20	1.19	30.60
1	1.500	39.70	1.60	42.20	1.55	39.80
1 1/8	1.900	49.80	2.03	53.00	1.96	50.10
1 1/4	2.340	61.00	2.50	65.00	2.42	61.50

EXPEDIENT FIELD DESIGN

8-29. The expedient field design may be necessary. To determine the tension in a cable for a given span and load, use *Table 8-3, page 8-10,* as follows:

- **Column 1.** Find the sag ratio.
- **Column 2.** Use this data when designing suspension bridges to determine the cable tension when a uniform load is suspended along a horizontal span. Multiply the appropriate tension factor in Column 2 by the uniform load and by the span length.
- **Column 3.** Use this data to determine the cable tension in an unloaded cableway. Multiply the weight per foot of cable by the appropriate tension factor in Column 3 and by the length of the cable to obtain the cable tension.

- **Column 4.** Use this data to compute the cable length that is between the supports. Multiply the span length by the length factor in Column 4.

BACKSTAYS

8-30. Backstays are the portions of the main cables that are behind the towers. Ensure that the maximum allowable tension of the cable is not exceeded. Compute the tension in the backstays by multiplying the results of *equation 8-7* by the secant of the horizontal backstay angle. For equal tension in the cables on both sides of the tower, the backstay angle should be as follows:

$$sec = \sqrt{1 + 16\left(\frac{y_s}{L}\right)^2} \qquad (8\text{-}12)$$

where—

sec = *secant of the cable deflection angle*
y_s = *cable sag, in feet (paragraph 8-10)*
L = *span length, in feet*

TOWERS

8-31. In most cases, construct towers at the site. After determining the type of installation and the cable sag, determine the tower height from the field profile. Keep towers as low as possible to simplify the design and construction. The main consideration is the timber size required. *Figure 8-7, page 8-14,* shows examples of improvised towers. Compute the tower height as follows:

$$h = L(y_s + c) + L_{cs} \qquad (8\text{-}13)$$

where—

h = *tower height, in feet*
L = *span length, in feet*
y_s = *cable sag, in feet (paragraph 8-10)*
c = *camber, as a percentage (paragraph 8-11)*
L_{cs} = *length of center suspender, in feet*

LOADS

8-32. The cable (on both sides of the tower) places horizontal and vertical loads on the tower, depending on the angle of approach. The guy lines resist the horizontal load, placing an additional vertical load on the tower. *Table 8-5, page 8-14,* shows the vertical reactions on the tower for varying sizes of cable, sags, and slopes.

POSTS

8-33. Vertical reactions of the main cables determine the post size of the towers. For simplicity, a 12- x 12-inch post will carry loads of up to 2 1/2-ton trucks. However, use *Table 8-5* and *Table 8-6, page 8-15,* if determining a minimum size. Determine the maximum vertical reaction for a particular sag ratio, slope, tieback, and cable size from *Table 8-5*. Using this value,

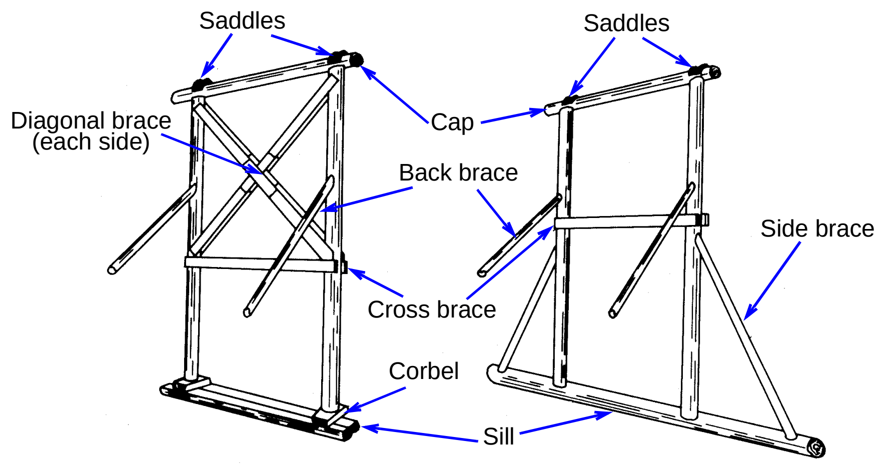

Figure 8-7. Improvised Suspension-Bridge Towers

Table 8-5. Vertical Reactions on Towers

Sag (%)	Slope (%)	Track-Cable Diameter (in)							
		3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
1:2 Tieback Ratio									
5.0	0	2,020	3,450	5,300	7,570	10,290	13,430	16,900	—
7.5	0	2,170	3,710	5,680	8,130	11,050	14,430	18,150	—
10.0	0	2,320	3,970	6,080	8,690	11,810	15,420	19,400	—
10.0	10	2,450	4,190	6,430	9,120	12,490	16,305	20,520	—
10.0	20	2,700	4,620	7,070	10,120	13,750	17,960	22,950	—
10.0	30	2,930	5,000	7,670	10,970	14,900	19,460	24,480	—
10.0	40	3,180	5,440	8,340	11,930	16,200	21,160	26,630	—
10.0	50	3,420	5,840	8,950	12,800	17,390	22,710	28,570	—
15.0	40	3,420	5,840	8,950	12,800	17,390	22,710	28,570	—
1:4 Tieback Ratio									
5.0	0	1,240	2,120	3,240	4,640	6,298	9,130	—	10,350
7.5	0	1,400	2,380	3,650	5,220	7,090	9,260	—	11,650
10.0	0	1,550	2,650	4,055	5,810	7,890	10,300	—	12,960
10.0	10	1,800	3,080	4,720	6,750	9,171	11,980	—	15,070
10.0	20	2,060	3,510	5,380	7,700	10,460	13,670	—	17,190
10.0	30	2,340	4,000	6,130	8,770	11,915	15,560	—	19,580
10.0	40	2,590	4,430	6,790	9,710	13,190	17,230	—	21,680
10.0	50	2,660	4,550	6,970	9,980	13,550	17,690	—	22,260
15.0	40	2,660	4,550	6,970	9,980	13,550	17,690	—	22,260

determine a post size from *Table 8-6*. The area, the modulus of elasticity, and the allowable stress must be known to determine a post size. Divide the length (in inches) by the minimum depth (in inches). Compute the post capacity by multiplying the allowable stress by the area. Brace the tower and place saddles *(Figure 8-8)* on top of the posts to protect them from the cables. Choose a post with a capacity greater than the maximum vertical reaction.

Table 8-6. Working Stress for Timber Columns

Modulus of Elasticity (E)	Length Divided by Depth							
	15 or Less	20	25	30	35	40	45	50
1,000,000	1,800	1,125	720	500	366	282	222	180
1,100,000	1,800	1,230	790	550	404	309	245	196
1,200,000	1,800	1,350	862	600	441	337	267	216
1,300,000	1,800	1,460	930	650	479	366	290	234
1,400,000	1,800	1,575	1,010	700	515	395	311	252
1,500,000	1,800	1,675	1,080	750	550	422	333	270
1,600,000	1,800	1,800	1,150	800	588	450	356	288
1,700,000	1,800	1,800	1,225	850	624	479	378	306
1,800,000	1,800	1,800	1,295	900	660	507	400	324
1,900,000	1,800	1,800	1,370	950	696	534	422	342
2,000,000	1,800	1,800	1,440	1,000	735	562	444	360

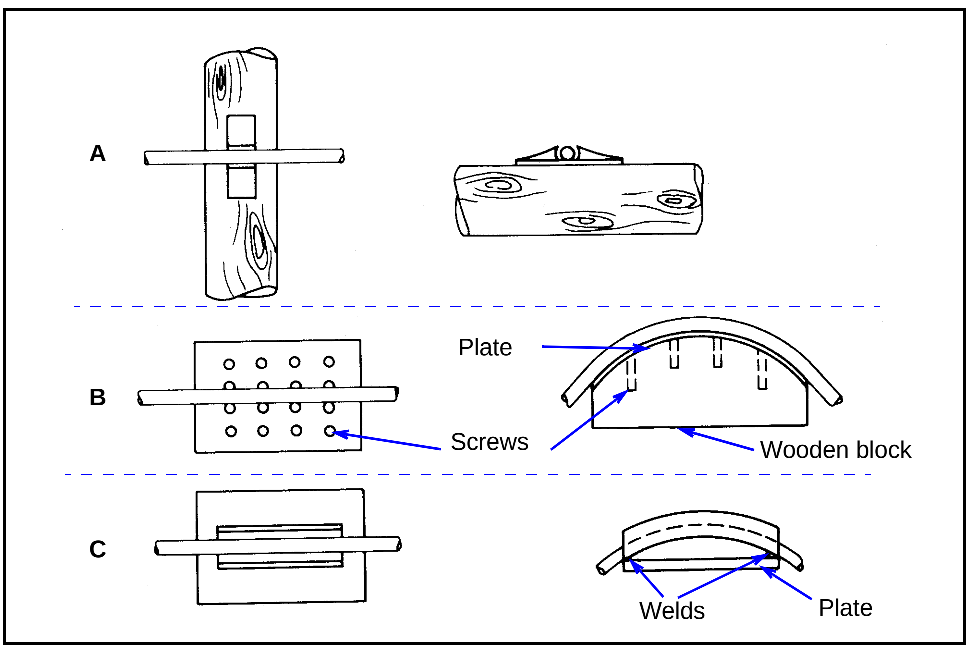

Figure 8-8. Saddles

SADDLES

8-34. Saddles may be required to protect timber cross members when using heavy cables or long spans. Make the saddles from sheet steel or pipe. The strap shown in *Figure 8-8A, page 8-15*, can easily be made from scrap steel. Indent the strap to position and steady the cables. *Figure 8-8B* shows a heavier plate and saddle-block combination. Hold the cable in place by partially driving the nails on either side of the cable. The saddle block and plate can be used on flat timbers to allow for curvature of the cable. *Figure 8-8C* shows a pipe saddle. Use it where several cables or a heavier cable is required. Saddles made from 1/2-inch steel plates are sufficient for cables up to 1 1/2 inches in diameter.

GUY LINES

8-35. Guy lines take up the horizontal forces on the tower. Four 3/8-inch-diameter wire ropes are usually enough to hold a tower in place, provided their slope is 2 feet of run to every foot of rise. This distance provides a margin of safety and allows considerable latitude in placing guy lines at an angle to the direction of the cable.

ANCHORAGES

8-36. For speed and economy, use natural anchors in cableway and tramway installations wherever possible. Other temporary anchors include pickets, rock anchors, holdfasts, and deadmen. Fabricate permanent anchors of steel and set them in concrete or fasten them to permanent structures. Always fasten the guy lines to the anchors as near to the ground as possible so that they leave the anchor as parallel to the ground as possible (except in the case of rock anchors). The wedging action of a rock anchor is strongest under a direct pull and should be set with this effect in mind.

8-37. Trees, stumps, or rocks can serve as natural anchors for expedient work in the field. Avoid using a rotten tree or stump or a dead tree as an anchor. It is always advisable to lash the first tree or stump to a second one to provide added support. A transom *(Figure 8-9)* provides a stronger anchor than a single tree. When using rocks as natural anchors, examine the rocks carefully to be sure that they are large enough and firmly embedded in the ground. An outcropping of rock or a heavy boulder lying on the ground will serve as a satisfactory anchor. See *FM 5-125* for more detail on anchors.

PICKET HOLDFAST

8-38. One factor in the strength of a picket holdfast is the holding power of the ground. Strengthen the holdfast by increasing the surface area of the pickets against the ground. Drive two or more pickets into the ground and lash them together to form a stronger holdfast than a single picket. Make a multiple-picket holdfast as follows:

- Drive round pickets (at least 3 inches in diameter and 5 feet long) about 3 feet into the ground, spaced 3 to 6 feet apart in line with the guy line *(Figure 8-10A)*.

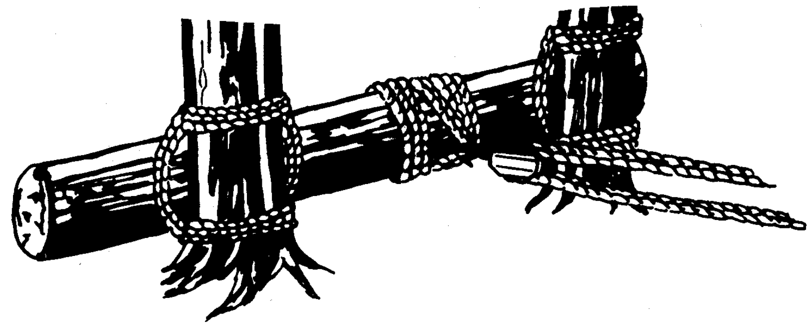

Figure 8-9. Transom

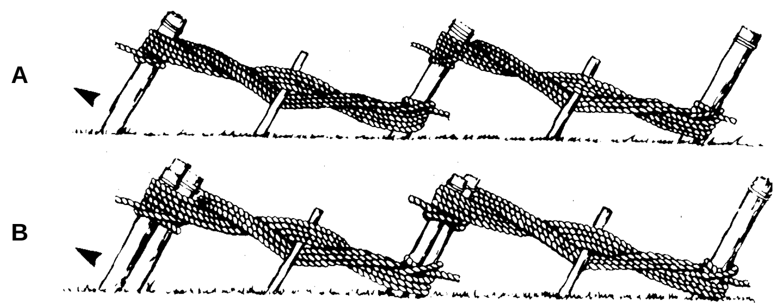

Figure 8-10. Picket Holdfasts

- Slope the pickets about 15 degrees from the vertical, opposite the direction of the pull.
- Tie a fiber rope to the first picket with a clove hitch, and take four to six turns around the two pickets from the bottom of the second picket to the top of the first. Fasten the rope to the second picket with a clove hitch just above the turns. Pass a stake between the rope turns.
- Tighten the rope by twisting the stake and then drive the stake into the ground.
- Place a similar lashing between the second and third pickets. If using wire rope for lashing, make only two complete turns around each pair of pickets. If neither fiber nor wire rope is available for lashing, nail boards between the pickets, from the top of the front picket to the bottom of the second picket.

8-39. The main strength of a multiple-picket holdfast is in the strength of the first, or front, picket. To increase the surface area of the first picket against the ground, drive three or four pickets into the ground close together. Lash this picket group to a second picket group, and lash the second group to a third picket group *(Figure 8-10B, page 8-17)*. Ash pickets (installed as outlined above) should withstand the following pulls in undisturbed, loamy soils:

- Single picket–700 pounds.
- 1-1 picket holdfast combination–1,400 pounds.
- 1-1-1 picket holdfast combination–1,800 pounds.
- 2-1 picket holdfast combination–2,000 pounds.
- 3-2-1 picket holdfast combination–4,000 pounds.

COMBINATION HOLDFAST

8-40. For heavy loading of an anchor, spread the load over the largest possible area by increasing the number of pickets. A combination holdfast has four or five multiple-picket holdfasts (parallel to each other) with a heavy log resting against the front pickets to form a combination log-picket holdfast *(Figure 8-11)*. Fasten the guy line or anchor sling to the log that bears against the pickets. The log should bear evenly against all pickets to obtain maximum strength. The strength of the log will affect the strength of the combination as much as the strength of the individual picket holdfasts. Carefully select the timber to stand the maximum pull on the line without appreciable bending. A steel cross member will serve the same function, forming a combination steel-picket holdfast *(Figure 8-12)*.

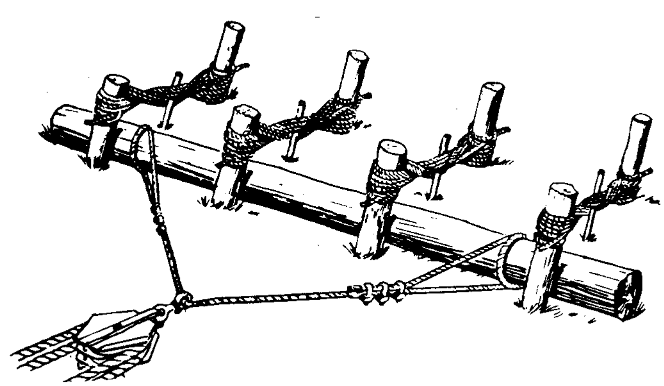

Figure 8-11. Combination Log-Picket Holdfast

ROCK ANCHOR

8-41. A rock anchor *(Figure 8-13)* has an eye on one end. The other end is threaded and has a nut, an expanding wedge, and a stop nut on it. Insert the threaded end of the rock anchor in the hole, with the nut clear of the wedge. After placing the anchor, insert a crowbar through the eye of the rock anchor and twist the crowbar. Doing this causes the threads of the rock anchor to draw the nut up against the wedge, forcing the wedge out against the sides of the hole in the rock.

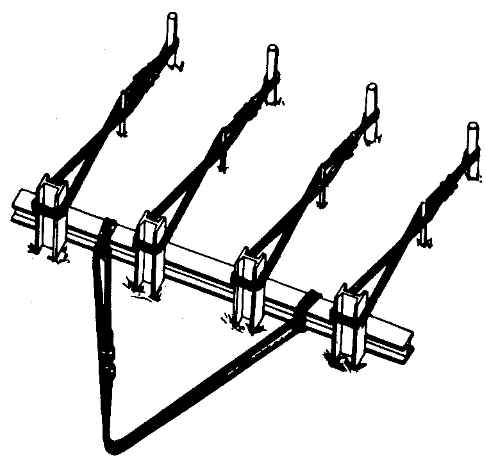

Figure 8-12. Combination Steel-Picket Holdfast

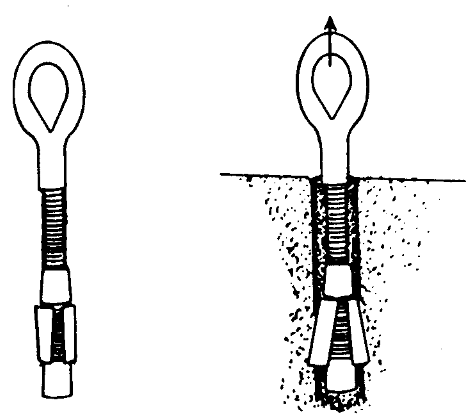

Figure 8-13. Rock Anchor

8-42. Since the wedging action is strongest under a direct pull, always set rock anchors so that the pull is in direct line with the shaft of the anchor. Drill holes for rock anchors 5 inches deep. In hard rock, use a 1-inch-diameter drill. In soft rock, use a 3/4-inch-diameter drill. Drill the hole as neatly as possible so that the rock anchor will develop maximum strength. In extremely soft rock, use a different type of anchor as the wedging action may not give sufficient holding power.

DEADMAN

8-43. A deadman consists of a log buried in the ground with the guy line or anchor sling connected to it at its center *(Figure 8-14)*. A deadman provides greater strength than a holdfast under most conditions. It is more suitable for permanent installation, and it is the best form of anchor for heavy loads because of the large surface area presented against the undisturbed soil. In some installations, it may be necessary to slacken or tighten the guy lines by putting in a turnbuckle near the ground or installing a take-up tackle.

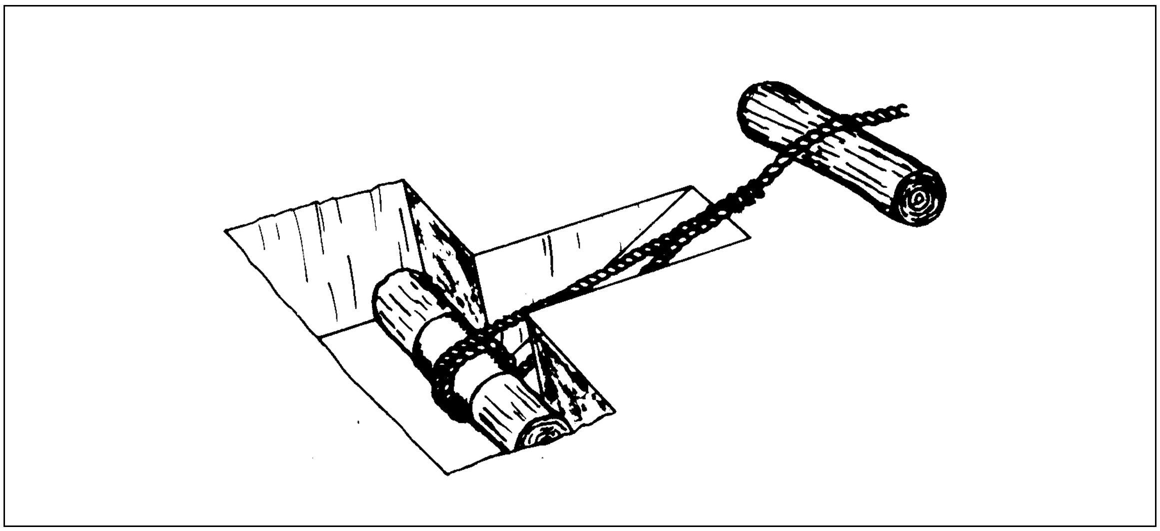

Figure 8-14. Log Deadman

8-44. Bury the deadman as deep as necessary for good bearing on solid ground. Follow these steps:

Step 1. Undercut the bank in the direction toward the guy line at an angle of about 15 degrees from the vertical. This will use as much of the surface of the undisturbed earth as possible.

Step 2. Drive stakes into the bank at several points over the deadman to increase the bearing surface.

Step 3. Cut a narrow, inclined trench for the guy line or anchor sling through the bank, leading to the center of the deadman. Place a short beam or log on the surface of the ground under the guy line or anchor sling at the outlet of the inclined trench, if possible.

Step 4. Fasten the guy line or anchor sling securely to the center of the deadman so that the standing part of the line (on which the pull occurs) will lead from the bottom of the deadman. This reduces the tendency of the deadman to rotate upward out of the hole.

Step 5. Clip the running end of the guy line securely to the standing part. The strength of the deadman depends partly on the strength of the buried log, but the main strength is the holding power of the earth. *Table 8-7* lists the deadman holding power in ordinary earth.

Table 8-7. Deadman Holding Power in Ordinary Earth

Mean Anchor Depth (ft)	Safe Resistance (lb/sq ft) of Deadman Area by Inclination of Pull (Vertical to Horizontal)				
	Vertical	1:1	1:2	1:3	1:4
3	600	950	1,300	1,450	1,500
4	1,050	1,750	2,200	2,600	2,700
5	1,700	2,800	3,600	4,000	4,100
6	2,400	3,800	5,100	5,800	6,000
7	3,200	5,100	7,000	8,000	8,400

8-45. Design and place bearing plates where the cable is in contact with, or bears on, the log or squared timber deadman. The bearing plate prevents the cable from cutting through the timber. *Table 8-8, page 8-22,* shows the required size of the bearing plate based on cable and deadman sizes. See *TC 5-210*, *FM 5-125*, or *FM 5-34* for more information about a deadman.

Table 8-8. Bearing-Plate Dimensions

Deadman Face (in)	Dimension	Cable Size (in)							
		3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
8	x	7/16	7/8	1 1/4	—	—	—	—	—
	y	4	8	11	—	—	—	—	—
	z	6	6	6	—	—	—	—	—
10	x	7/16	11/16	1	1 3/8	—	—	—	—
	y	4	6	9	12	—	—	—	—
	z	8	8	8	8	—	—	—	—
12	x	7/16	9/16	13/16	1 1/8	1 7/16	—	—	—
	y	4	5	7	10	13	—	—	—
	z	10	10	10	10	10	—	—	—
14	x	7/16	7/16	11/16	7/8	1 1/4	1 9/16	2	—
	y	4	4	6	8	11	14	18	—
	z	12	12	12	12	12	12	12	—
16	x	7/16	7/16	9/16	13/16	1 1/8	1 3/8	1 11/16	2 1/8
	y	4	4	5	7	10	12	15	19
	z	14	14	14	14	14	14	14	14
18	x	7/16	7/16	7/16	11/16	7/8	1 1/4	1 9/16	1 13/16
	y	4	4	4	6	8	11	14	16
	z	16	16	16	16	16	16	16	16
20	x	7/16	7/16	7/16	11/16	7/8	1 1/8	1 3/8	1 11/16
	y	4	4	4	6	8	11	14	16
	z	18	18	18	18	18	18	18	18
24	x	7/16	7/16	7/16	9/16	11/16	7/8	1 1/8	1 3/8
	y	4	4	4	5	6	8	10	12
	z	22	22	22	22	22	22	22	22

NOTE: The values in this table are based on the use of IPS cable.